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# Introduction to the SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) Project

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The SCALE-UP Project has established a highly collaborative, hands-on, computer-rich, interactive learning environment for large-enrollment courses. Class time is spent primarily on hands-on activities, simulations, and interesting questions as well as hypothesis-driven labs. Students sit in three groups of three students at round tables. Instructors circulate and work with teams and individuals, engaging them in Socratic-like dialogues. Rigorous evaluations of learning have been conducted in parallel with the curriculum development effort. Our findings can be summarized as follows: Ability to solve problems is improved, conceptual understanding is increased, attitudes are improved, failure rates are drastically reduced (especially for women and minorities), and performance in follow up physics and engineering classes is positively impacted

In this paper we will describe the studio-style classroom environment and discuss how its features promote the desired interactions. We will also show results of a variety of assessments of student learning.

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## 1 – Studio-style Classes

> "…I point to the following unwelcome truth: much as we might dislike the implications, research is showing that didactic exposition of abstract ideas and lines of reasoning (however engaging and lucid we might try to make them) to passive listeners yields pathetically thin results in learning and understanding–except in the very small percentage of students who are specially gifted in the field."[1]

It is known that students can learn more physics in classes where they interact with faculty, collaborate with peers on interesting tasks, and are actively involved with the material they are learning[2, 3, 4, 5, 6]. Research on learning and curriculum development has resulted in instructional materials that can correct many of the shortcomings of traditional physics instruction. Careful study of these research-based introductory curricula in small classes indicate that they can significantly improve students' conceptual understanding[2, 7, 8, 9, 10]. However, introductory physics instructors with large classes who want to incorporate active learning into their classrooms must typically choose between (1) hands-on activities[11] in small recitation or laboratory sections that supplement the lecture[12] and (2) interactive lecture activities for larger classes like Peer Instruction[3, 13] and Interactive Lecture Demonstrations[14] that do not permit hands-on experiments and limit faculty interactions with individual groups. Studio-style[15] classes, where students work in teams observing and studying physical phenomena, offer faculty a third option.

Studio/workshop classes like SCALE-UP give instructors another choice by replacing the lecture/laboratory format with 4-6 hours of activity-based instruction per week, typically in 2-hour blocks. This format has several advantages over the traditional lecture/laboratory format. Since the entire class is taught in the same room with the same students and instructors in each class, all activities, including laboratory experiments, can be arranged to build on one another in sequence for greater learning impact[16] than when some activities are taught in small sections running parallel to the lecture course. When a lab section is taught as a separate course, it is often either weeks or at best a few days ahead of or behind the lecture and for some students, the lab course is not even taken in the same term as the lecture. In addition to better integration of lab experiments into the course, a studio format also allows for a greater variety of hands-on activities including microcomputer-based laboratory (MBL) and simulations since each student group can have access to a computer and lab equipment during any part of the course. Last but not least, in an interactive lecture, students can avoid instructors by hiding in the middle of the row, away from the aisles. In the studio format, instructors can freely circulate and interact with any group at any time.

There are several examples of workshop/studio-style curricula in the Physics Education Research (PER) literature[17] including the Workshop Physics curriculum developed at Dickinson College[18] and the Studio Physics curricula at RPI[19] and Cal Poly San Luis Obispo[20]. These curricula have the advantages described above, but are difficult to implement at large research universities because of class size limitations. The SCALE-UP project is an effort to create studio classes that would be large enough to provide an effective, yet affordable alternative to large classes taught via the standard lecture/laboratory format.

As with the other research-based curricula described above, in SCALE-UP classes the students work through activities in small groups of 3-4 students each. However, in SCALE-UP classes, both the activities and the classroom have been modified for larger student/faculty ratios of 25-50 to 1, which permits class sizes of 50-120 students with 2-4 instructors (faculty & TAs). Thus SCALE-UP makes it practical to offer activity-based classes with integrated hands-on labs even at schools like North Carolina State University (NCSU) and the University of Central Florida (UCF), where thousands of students are enrolled in the introductory physics classes each year. This format takes advantage of cooperative learning techniques and helps students form learning communities which can make education at large universities seem much less impersonal, particularly for students taking mainly large introductory classes in their freshman and sophomore years. Interactions between students and with faculty are the most important aspect of a successful college career.[21]

## 2 – Cooperative Groups of Students

There are many benefits to placing students into formal cooperative groups. Because they talk with each other, they are naturally more active (or interactive). Obviously, when an individual student reaches an impasse they are stuck. Calling on teammates can provide additional resources and avenues to success. Seeing how others approach problems can be very valuable, especially for students whose performance is low. Also, by careful design of instruction, students can be placed into situations where they work at the upper levels of Bloom's taxonomy—synthesis and evaluation of each other's ideas. Perhaps most importantly, grouped students benefit from cognitive rehearsal: they learn more when they teach others.

Johnson, Johnson, and Smith[22] present five required characteristics of successful group-based instruction. There has to be individual accountability, positive interdependence, opportunities for interaction, appropriate use of interpersonal skills, and regular self-assessment of group functioning. We have found that not incorporating all these aspects is a recipe for failure, at least as far as group functioning is concerned.

We have incorporated several instructional methods to ensure each of the above characteristics is present. For example, we have found ways of dealing with two types of students who don't want to participate in groups. The better students often don't want to work with their peers because they believe they will be "slowed down" by the poorer students. (They don't recognize what they themselves gain while explaining concepts to others.) Because these students are many times motivated by grades, we offer five "teamsmanship points" to each member of any group whose exam average is 80% or better. Low-end students often don't want to participate in a group because they are lazy. Since they tend to avoid work, we provide a mechanism whereby they can be "fired" from their group for poor performance. While this sounds silly, in practice it means they would have to do the entire group's work by themselves—highly undesirable to a student trying to avoid work. Having students write their own contracts helps students manage their own group operation.

Efforts are made to ensure heterogeneity within groups and homogeneity between them. At the beginning of the semester the students are ranked by an appropriate measure of their background (FCI pretest scores, grades from previous physics courses, GPA, etc.). Each group has one student from the top, middle, and bottom third of the class ranking. We make sure each table has one of the very best students and also select group members so that no female or minority students are by themselves. We have found it best to create new groups every few weeks, typically after an exam. Waiting longer causes problems because of the strong friendships that tend to form in long-established groups, leading to reluctance to later group resuffling. We find we do not need to be as careful about matching female and minority students in the later groups.

## 3 – The Learning Environment

We redesigned the classroom environment to better promote active, collaborative learning. Taking a cue from a typical restaurant layout, we utilize round tables with comfortable chairs placed around them. This was not done without considerable experimentation. We tried placing students at rectangular tables, but observed their difficulty in communicating with each other. Once we decided on the table shape, we tested diameters of 6, 7, 9, and 10 feet. Although interviews and class observations revealed the students' preferences for the larger tables, we found they did not facilitate between-group discussions. A person across the table was simply too far away. The 7-foot tables appear to be the best compromise between "elbow room" and closeness for conversation, although they are not an industry-standard size. (See Fig. 1a.) Tables that are only 6 feet in diameter can be used when the room dimensions demand it, but the students will feel quite cramped. Each table seats three teams (called A, B, and C) of three students. The tables are numbered so a specific team can be identified (*e.g.* Group 4C), an entire table can be selected (*e.g.* Table 3), the entire room can be divided in half by specifying even and odd table numbers, or the room can be split into thirds by calling on all the "A groups" to do one task while the "B groups" and "C groups" work on their own activities. Each individual student has their own nametag so that no one can be anonymous, even in a large classroom.

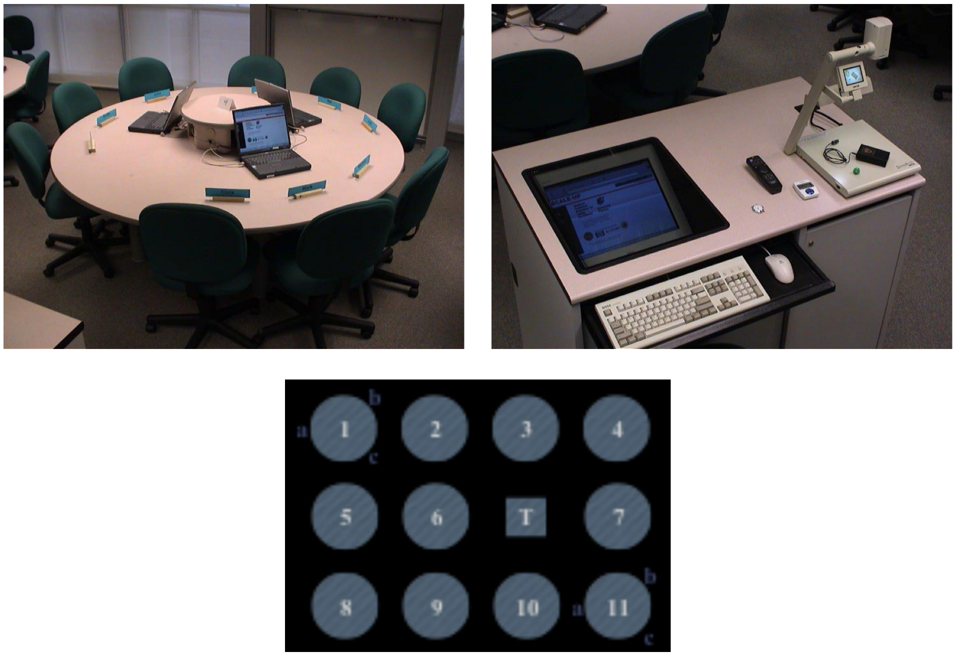



*Fig. 1. (a) Seven-foot diameter table, seating three teams of three students. (b) Rectangular instructor station with computer and video presenter. (c) Schematic classroom layout showing numbering of tables and letter labels of groups. The teacher station is near the center of the room. This particular room arrangement seats 99 students.*

The instructor station (Fig. 1b) is a smaller table or podium that is placed near the center of the room. It is outfitted with a computer and video presentation system (basically a video camera mounted on a stand). Both of these devices are connected to ceiling-mounted projectors. We have not experimented much with the design of the instructor station, so we have no other recommendations other than suggesting you test the working heights of both the keyboard and the video presenter for use by different instructors as they are standing.

We examined the number and placement of computers in the classroom. We have found that one laptop computer per team is sufficient. (If you want to give web-based quizzes or tests, you may need to increase this number.) Laptops are preferred to desktop systems because of their smaller "footprint" and lower monitor height. It is also very helpful to tell students to close the lids of their computers when they are being distracted by the ever-present Internet and *Instant Messenger*.

Large white boards mounted on the walls (and/or smaller, portable group boards) have multiple benefits. Since students do their "thinking" on these public spaces the instructor can more easily see how groups are progressing during an activity. In addition, students can view/critique each other's boards while working or as a tool for presentation to the entire class. A whiteboard can be seen behind the table in Fig. 1a.

We have also found a wireless microphone to be helpful when the instructor wants everyone's attention. The majority of classtime is spent with the students working in groups as the instructor and assistant(s) circulate throughout the room. Getting students to look away from an engaging task is much easier if they don't know if the instructor trying to get their attention is across the room or right behind them!

## 4 – Engaging Activities

A major advantage to having student groups working on activities is that it frees instructors from standing in the front of the room. A faculty member, graduate student, and if possible an undergraduate are sufficient to monitor the work of 99 students. Walking around the room and glancing at whiteboards provides considerable feedback to the teachers. Progress is ensured by engaging students in semi-Socratic dialogs[23]. A careful balance must be maintained between continually asking questions and students feeling like they will never hear an answer from the instructor. By strongly encouraging acceptable answers and providing end-of-activity summaries (by teachers and students), students feel they reach closure for a particular task. This must be done while not disparaging incorrect answers. We want students to take risks, so instructors must try to find something to praise, even as they carefully guide the students from a misunderstanding toward the desired goal. For example, students displaying the classic "charge is consumed in a resistor" error can be asked questions about charge conservation to facilitate their accepting current as a circulation of charges. Then they can be helped to understand that it is energy that is "used up" in a resistor (in the sense that it is changed into heat) and that perhaps that concept is what they were thinking about originally. This type of interchange takes practice on the instructor's part and training of teaching assistants. It is especially important that teachers don't try to "show what they know" by simply telling students the right answer. This is truly a situation where the teacher is the guide at the side and not the sage on the stage. Nature is the authority, not the book or instructor.

To relieve some of the burden from instructors, we have created a large set of research-based lesson plans. In some cases these are entirely new materials, in others we have modified existing curricula. For example, we found that the effectiveness of the popular Washington *Tutorials*[12] suffers when used with 99 students at once. This is probably because the student/faculty ratio is much larger than the developers had in mind. We have taken the activities, modified them in most cases, and then broken them up into 10 to 15 minute tasks that are delivered via the web. (We password protect the activities so that students can't start them early. We want them interacting with each other and the instructors while they are working.)

To keep the class interesting we have several different types of group activities. *Tangibles* are short tasks where students make some sort of hands-on measurement or observation. Examples include determining the thickness of a single sheet of paper in their textbook (for practice with significant figures and estimating), calculating the number of excess charges on a piece of transparent tape after it is pulled up from the tabletop, determining the desired spacing of frets on a guitar, or estimating the amount of force needed to roll a racquetball along a circular arc. *Ponderables* similarly require estimating or finding values from the web, but there are no observations needed. We ask students questions like “Estimate the number of steps it takes to walk across the country.” or “How far does a bowling ball skid before its motion is purely rolling?” These questions are hard enough that students appreciate having their teammates available to help. They also evaluate the quality of other groups’ efforts.

We make software available for students to use as they grapple with difficult concepts. Simulation packages, spreadsheets, and concept-oriented programs are used extensively. Many are Java-based, like *Physlets*®[24], and are delivered via the web. An important aspect to realize is that the simulations are used to help students more thoroughly understand the real world and are not a substitute for hands-on experience.

We have made substantial changes to the labs we have students work on during the semester. Because we don’t have to rely on labs to be the only place where students “do physics” we can concentrate on other areas like uncertainties, hypothesis testing, and experimental design. For example, one lab has them taking static measurements of a mass/spring system and then predicting what a graph of the oscillating vertical position of the mass would look like. Because students don’t realize the spring’s mass cannot be ignored in this particular situation, their predictions are wrong. They spend the rest of the time trying to isolate the problem and using software to model the spring as a series of small objects connected by stiffer springs.

We provide students with a problem solving protocol based on the work of George Polya[25]. GOAL is a mnemonic for easy recall. G reminds students to carefully *G*ather information by looking for key phrases, getting a “big picture” view of the situation, estimating the final answer, etc. O stands for *O*rganize and is where the problem is classified by the physics principles involved. A written plan of action and drawing help students clarify their thoughts (and assist instructors when they grade the solution). During the *A*nalysis step students carry out the calculations needed for a mathematical answer and then incorporate the numbers gathered initially. Finally, students must *L*earn from their work. They check the answer for reasonableness, correct units, etc. They look at limiting cases to see if their algebraic result behaves properly. They also consider what they should have learned from this particular problem. Without requiring this last step, students often write the final number down from their calculator and never give it a second thought. We want them to go through some of the thought processes their instructor considered when selecting or creating the problem: “What is the key idea in this problem? How is it different from earlier problems? How is it similar?”

## 5 –Educational Impact

We have employed a wide array of quantitative and qualitative methods to evaluate the educational impact of the SCALE-UP pedagogy. We have utilized classroom observers taking field notes as well as video cameras to record the action. The observer and/or camera can focus on a single group, a table, or how the entire class interacts with the instructor.

The engineering departments were especially interested in knowing if SCALE-UP students could still do typical exam problems, so we randomly sampled problems from a mechanics test and gave them to our students. The results are shown in Figure 2. The NCSU SCALE-UP students performed significantly better on all problems except items 10 and 11, which they had not yet covered in class. The same final E & M exam at the University of Florida was given to three lecture sections and a SCALE-UP class, as shown in Figure 3. While not as striking as the mechanics results, in general, the SCALE-UP students out-performed their peers when the material was covered for approximately the same amount of time in both SCALE-UP and traditional classes.

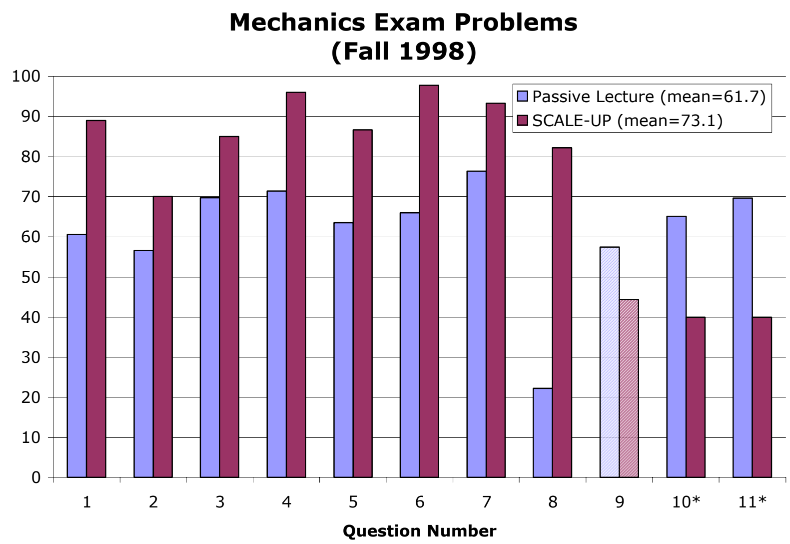
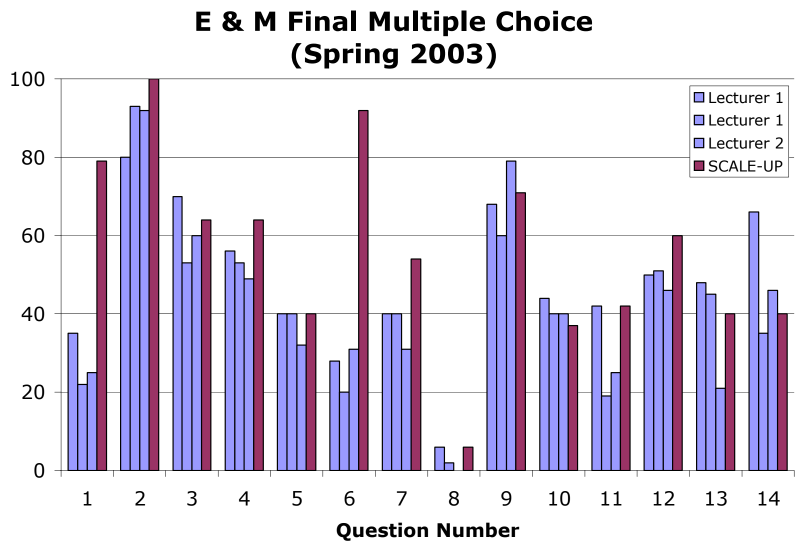



*Fig. 2. Comparison of traditional and SCALE-UP students using randomly selected questions from the traditional exam. Item 9 values are not significantly different at the 0.05 level. Items 10 and 11 were not covered in the SCALE-UP class.*



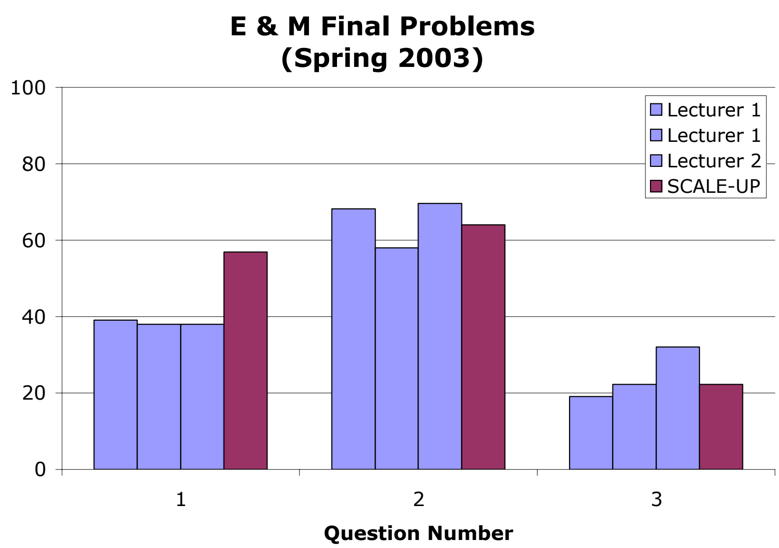




*Fig 3. Comparing students with typical exam questions.(a) Multiple choice results, (b) Problems requiring worked out solutions. Item 1 was well covered in SCALE-UP. Item 2 had a single ponderable. Item 3 had just a demonstration and ponderable.*

A very coarse, but still useful measure of educational impact is overall pass/fail rate. While not entirely comparable because requirements for traditional and SCALE-UP courses differed, we feel justified in this analysis since demands were much higher on the SCALE-UP students. (One traditional student mistakenly started taking a SCALE-UP test and asked, “Are we really supposed to know how to do these problems?”) Figure 4 shows failure rate ratios, calculated by dividing the percentage failing traditional courses by the percentage failing in SCALE-UP. This is over a five-year time span, from 1997 to 2002, and incorporates data from over 16,000 NCSU students. (A student was said to fail the mechanics course when they received a grade lower than C-, since that level of performance barred them from the E & M course. The second semester course was failed with a grade below D-.) The results for females and minorities are particularly interesting. We attribute their success to the social interactions common in the SCALE-UP environment, where risk-taking is encouraged. If an individual is confused by something, they simply ask their teammate. If their colleague knows the answer, it is explained it to them. If their friend is also confused, they realize they are not alone and will be encouraged to ask the instructor. External evaluators noted the higher quality and quantity of questions in the SCALE-UP classes as compared to the traditional courses.

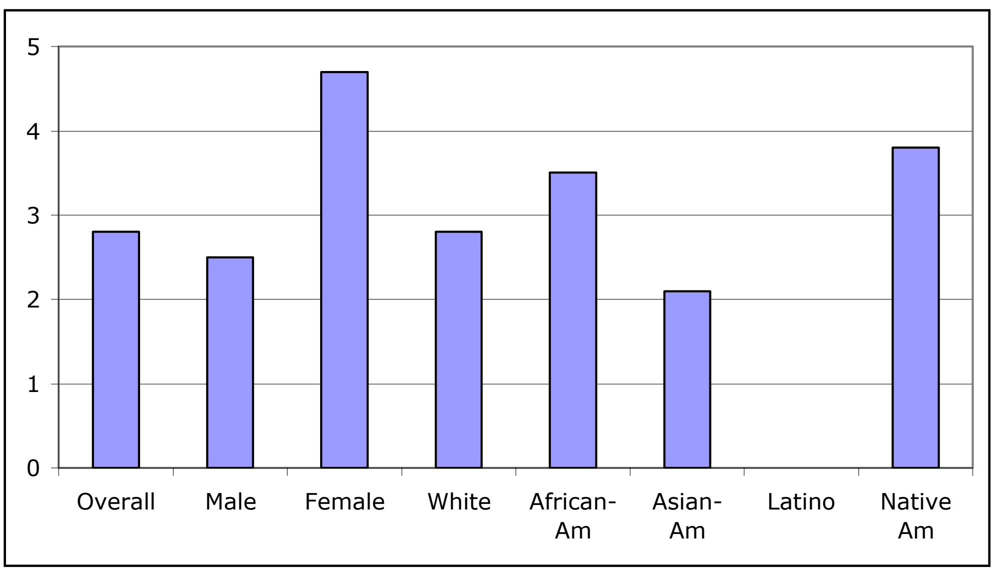



*Fig. 4. Ratio of failure rate percentages. Overall, students were nearly three times as likely to fail in a traditionally taught section than an equivalent SCALE-UP section of the course. The Latino ratio could not be calculated because no Latino students have failed in a SCALE-UP section.*

We also wanted to know if students were learning concepts, since research has shown that student success and ability to solve traditional problems does not necessarily require real understanding. We employed a variety of research-based tests. Figure 5 shows the FCI[26] results for a single instructor (RJB) teaching traditional and SCALE-UP mechanics. Hake's national sample results[2] are shown for comparison. It is clear the SCALE-UP students outperformed their traditionally-taught peers. You can also see when SCALE-UP class size changed from 54 to 99 in the fall of 1999. The benefits of smaller classes cannot be denied.

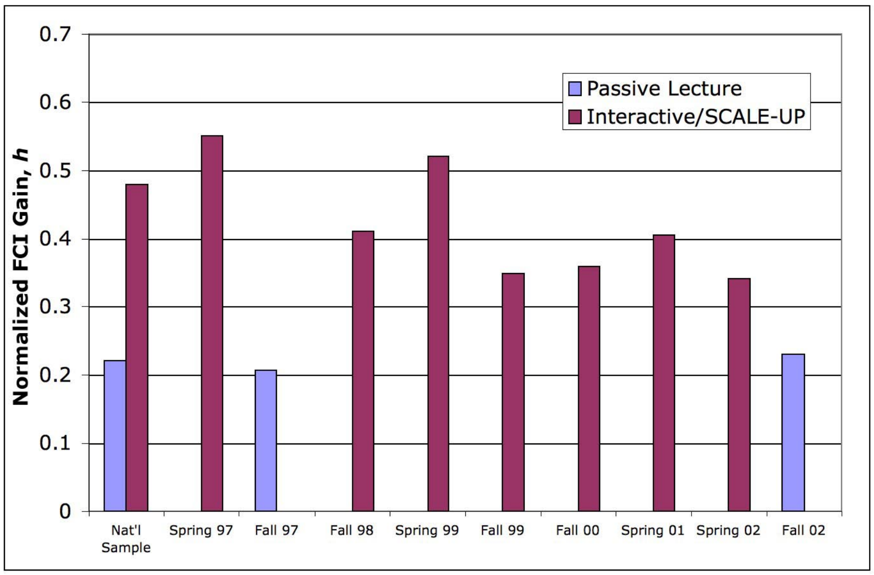



*Fig. 5. Normalized gains on the Force Concept Inventory for students of a single instructor.*

A common concern of those questioning the need for reform is that a great deal of effort seems to be spent "bringing up the low-end students," perhaps to the detriment of the better students. To see if that was a problem we examined conceptual test performance for the top, middle, and bottom students in the SCALE-UP classes. What we found is shown in Figure 6. The repeated patterns clearly show that it is the students in the top third of the class who benefit the most from the SCALE-UP pedagogy. We believe this is because they are probably the ones doing most of the peer-teaching within their group. What is particularly noteworthy are the data for the top MIT students, arguably the best students in the world. Evidently they have already gathered all they will learn from traditionally taught physics, as evidenced by the very small gain for that cohort. On the other hand, placing top MIT students in the SCALE-UP environment resulted in a huge gain, so there was obviously more to be learned.

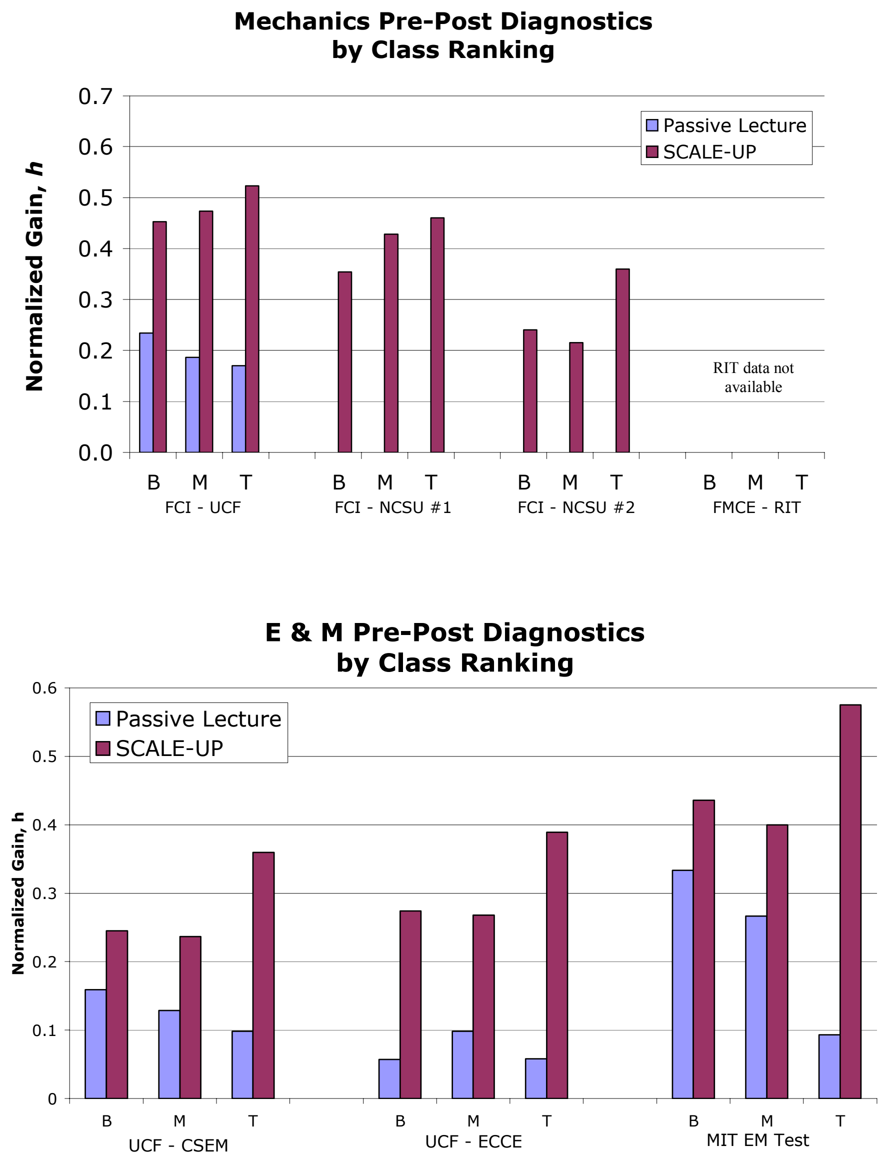



*Fig. 6. Students in the top third of their classes gained the most from the SCALE-UP experience.*

We wanted to assess students' attitudes about the class, but this is a difficult task. A rough measure is to compare attendance rates for students of the same teacher (RJB) when teaching both traditionally and in a SCALE-UP mode. The attendance requirements were identical: students could attend if desired, but there were no direct grade penalties for low attendance. Table 1 shows that not only was attendance better in SCALE-UP classes, but the spread of attendance rates was lower. The traditional sections always had a few people who rarely attended, driving up the standard deviation values. This was not the case in SCALE-UP.

| | **Lecture/Lab** | **SCALE-UP** |
|---:|:---:|:---:|
| # Classes | 3 | 6 |
| # Students | 263 | 342 |
| % Attendance | 75.2 | 90.3 |
| Std. Dev. | 24.0 | 11.6 |

*Table 1. Attendance rates for students of the same instructor, with the same attendance policy.*

Quotes from interviews also provide insight into how students viewed the SCALE-UP classes. It is interesting to compare the impressions students have of their colleagues in the following two quotes:

> "I can deal with the lecture class, it's just that I enjoy more...getting more into the interactive projects. It's more hands on. **If you don't understand something, you just ask the guy next to you.** Nobody yells at you for talking."

> "...you have a professor right in the middle and...a couple of guys spread out and you can flag them down...In the lecture, you are sitting...25 rows back. **You really don't have anyone but the two people next to you and they don't know.** You really don't have anyone with some knowledge to help you out."

The real test of an educational reform is student performance in later classes. We found that SCALE-UP Mechanics students do significantly better in their E & M course (whether the later course is taught traditionally or in the SCALE-UP mode). We found their performance slightly, but significantly worse than that of traditional students in Engineering Statics courses. This caused us concern until we realized that a substantially larger fraction of students are passing SCALE-UP sections. Those students would have never been admitted to the engineering course if they had taken a traditional physics course and failed. To see if this might be the case we used SAT scores as a way of identifying students at risk of failure in traditional physics. As we expected, there was no difference in passing rates for those students with Math SAT scores above 500. But of those students whose Math SAT was less than 500, 83% of the SCALE-UP students passed Engineering Statics compared to only 69%

of the traditionally-taught students. So physics is no longer the "filter" it used to be. What's more, students who probably would not have progressed toward an engineering degree with traditional physics instruction are succeeding in their later courses.

## 6 – Dissemination

A large number of schools have adopted the SCALE-UP approach and have adapted it to their particular circumstances. Figure 7 shows a few of their classrooms.

*Fig. 7. SCALE-UP classrooms at American University, University of Central Florida, MIT, and University of New Hampshire. Note the modified table design in the last photo.*

We are encouraging other institutions to adopt the SCALE-UP approach by providing classroom design assistance, presenting talks and workshops, and by producing a website[27] with lesson plans and teacher guides. This has been quite successful and the number of schools using this approach is increasing. We have also incorporated some of what we have learned from the SCALE-UP project and made changes in a "mainstream" physics text[28]. Tangible activities are called "QuickLabs" while ponderable activities are labeled "Quick Quizzes." The publisher reports a 50% increase in sales with the revised edition, making it the leading text in the nation. More than 1/3 of all science, math, and engineering majors in the US are using materials developed as part of the SCALE-UP project. Figure 8 shows samples of these from the book.

Assistance is available to any who are considering adopting this approach by sending an e-mail to beichner@ncsu.edu or by visiting the website.

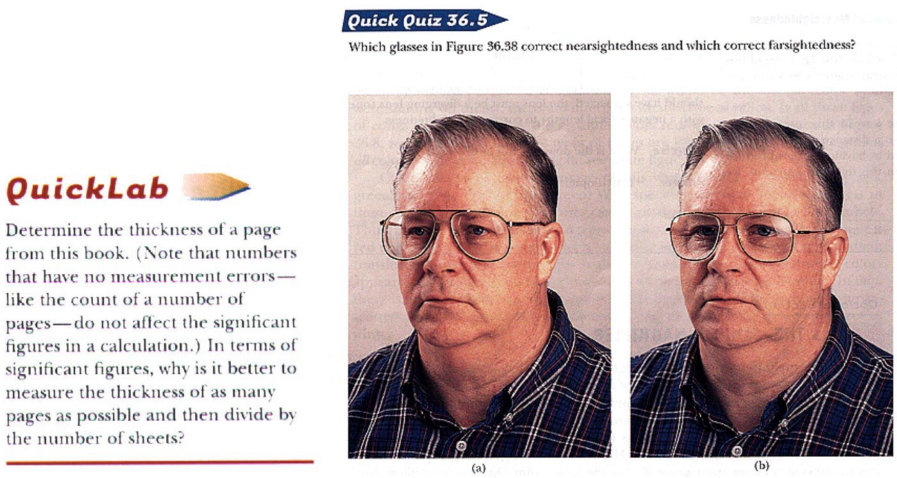



*Fig. 8. SCALE-UP materials made their way into Serway & Beichner's "Physics for Scientists and Engineers," used by more than 1/3 of all science, math, and engineering majors.*

## 7 – Acknowledgements

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